Journal of Engineering Science and Technology
Vol. 14, No. 3 (2019) 1314 - 1329

COMPARATIVE STUDY OF DIFFERENT SEISMIC CODES FOR REINFORCED CONCRETE BUILDINGS IN NORTHERN CYPRUS USING STATIC AND DYNAMIC METHODS

R. RESATOGLU*, M. K. A. HAMED

Near East University, Near East Boulevard, 99138,
Nicosia, North Cyprus, Mersin 10 Turkey
*Corresponding Author: rifat.resatoglu@neu.edu.tr

Abstract

This study presents a comparative evaluation between two seismic design codes, the Eurocode 8 (EC 8), which is well known and the seismic design code for Northern Cyprus, which was established in 2015. In order to make possible comparison among the codes, a particular location and the most common residential frame model has been chosen. In this research, buildings of the regular and irregular plan of Reinforced Concrete (RC) frames were analysed for low-mid-rise structures. Response Spectrum Method (RSM) and Equivalent Lateral Force Method (ELFM) were performed using Extended Three Dimensional Analysis of Building System (ETABS) software package. The aim of this study is to investigate the seismic provisions of the first edition of northern Cyprus seismic code to determine whether it provides a generic level of safety that incorporates in well-established code. The results obtained from both static and dynamic analysis are presented in the form of base shear, storey shear, axial forces and bending moments for selected columns for two different codes.

Keywords: Equivalent lateral force method, North Cyprus, Regular and irregular reinforced concrete frame, Response spectrum method, Seismic design code.

1. Introduction

1.1. Overview

Cyprus is the third biggest island in the Mediterranean sea with an area of 9251 km 2. It has a northern and southern part, as shown in Fig. 1. North Cyprus is divided into 5 districts namely; Lefkoşa (Nicosia), Gazimagusa (Famagusta), Girne (Kyrenia), Iskele and Guzelyurt as shown in Fig. 1. Nicosia is the capital city of north and south Cyprus. It is the only divided capital city in Europe. A case study is chosen for the northern half of Nicosia, also known as Lefkoşa. The northern Nicosia has a total population of 94824, where around one-third of the northern part whole population lives, according to the latest census, which was performed by the State Statistical Institute [1].

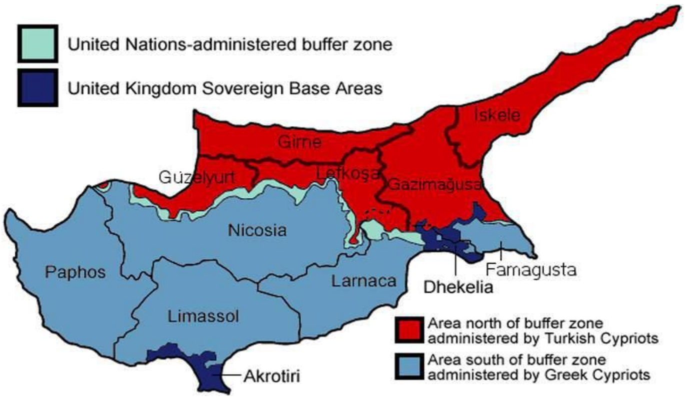

Fig. 1. Cyprus.

The island is known to have accommodated many communities and civilizations throughout its history. As a result of the movement of the population, because of the partition of the island into two, a housing necessity started to take places especially after 1974. Unfortunately, there is no current scientific building inventory information that conveys the current situation in northern Cyprus. The information obtained in the census carried out by the State Statistical Institute can be used to evaluate the total urban constructions, the building types according to usage and the residential buildings in the northern part of Nicosia. This statistical information is all presented in Figs. 2 to 4, respectively.

The majority of the existing building stock in the case study region is low-mid-rise RC buildings. RC buildings are very popular in northern Cyprus. This method of construction is applied in northern Cyprus as it is applied in many countries because the implementation of this method is convenient.

The whole island has always been vulnerable to various kind of disasters, and earthquakes are the most hazardous kind of these disasters. Ambrasey [2] explained that the latest significant earthquake hit the island in 1953 with a surface wave magnitude of 6.5 and caused 40 fatalities. Besides common loads applied to RC buildings, earthquake is one of the most hazardous actions they have to withstand. Many scientists have carried out several studies to understand the behaviour of this composite material and to propose a better solution against the natural event.

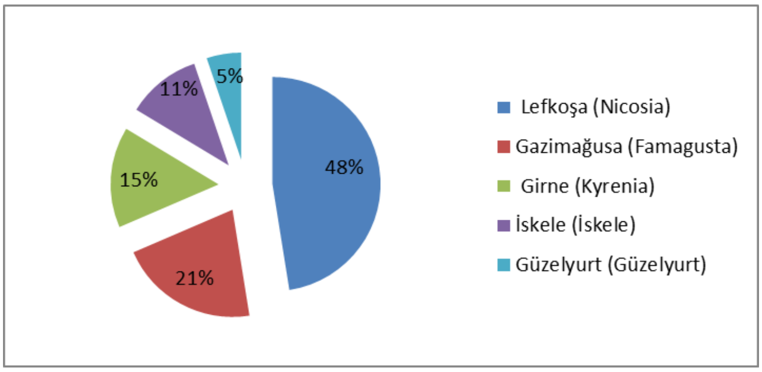

Fig. 2. Total urban constructions in northern Cyprus, 2015.

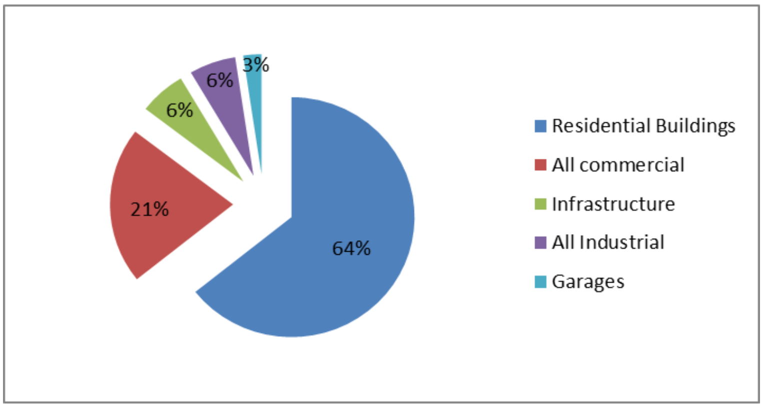

Fig. 3. Building types in northern half of Nicosia according to usage 2015.

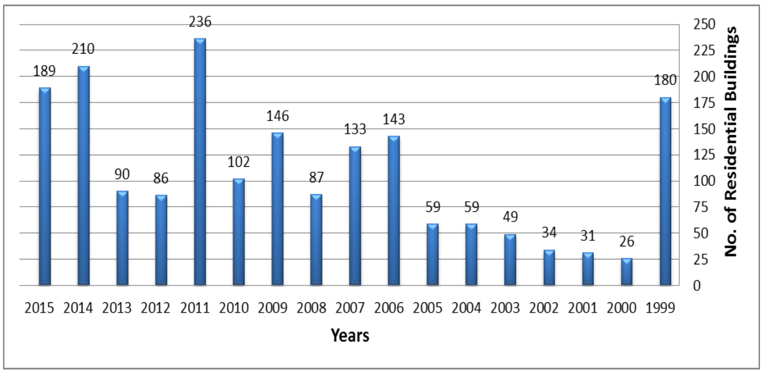

Fig. 4. Number of residential buildings in northern half of Nicosia.

Devastating earthquakes hit all around the world and caused many deaths and injuries and left many structures with substantial damage because of their weakness to withstand the earthquake events due to poor detailing of the seismic resisting building according to inadequate design codes. Since then, many seismic codes were published all around the world [3].

The Turkish earthquake regulation is being used for the northern part of the island and peak ground acceleration (PGA) values have been adopted to northern Cyprus in the time period until 2015. The recent version of the seismic design code in Turkey includes the issue of seismic safety assessment and retrofitting, which was published in 2007, (TEC 2007) [4]. Further information on Turkish seismic design code and its evolution by time can be found elsewhere [5-10].

The first seismic design code for buildings in northern Cyprus was established in 2015, which is called as "Regulation on buildings to be built in earthquake zones for northern Cyprus". This was the first national code where the government of that time felt the need for a legal enactment. This code will be nominated in the current paper as northern Cyprus seismic code (NCSC 2015).

Currently, two different design codes are used in Cyprus due to political issues. These are regulation on buildings to be built in earthquake zones for northern Cyprus (NCSC 2015) and Eurocode 8 (EC 8) for the southern part of the island, where the two code uses different seismic zone map and different peak ground acceleration (PGA) values. Seismic zones cited in this specification are the second and third seismic zones depict in seismic zoning map of northern Cyprus prepared and mutually consulted by the Chamber of Cyprus Turkish Civil Engineers and Ministry of Public Works and Transport department.

EC8 Cyprus National Annex provided seismic zoning map of Cyprus having the PGA value of 0.2 g for Nicosia is shown in Fig. 5 [11]. The seismic zoning map that has been adapted to the code in the northern part of the island is shown in Fig. 6 [12]. Compared to the EC 8 map, higher ground shaking values can be seen in the NCSC 2015 map.

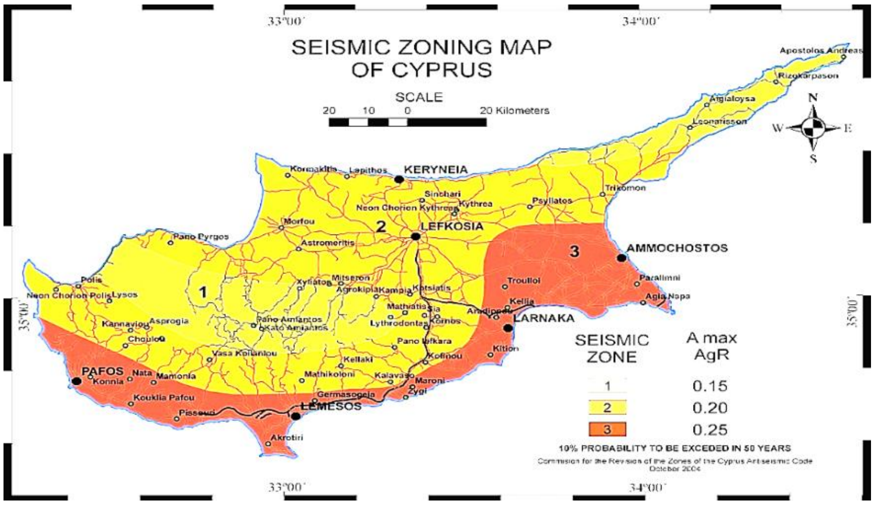

Fig. 5. Seismic map of Cyprus from EC 8 national annexe CYS EN 1998-1:2004.

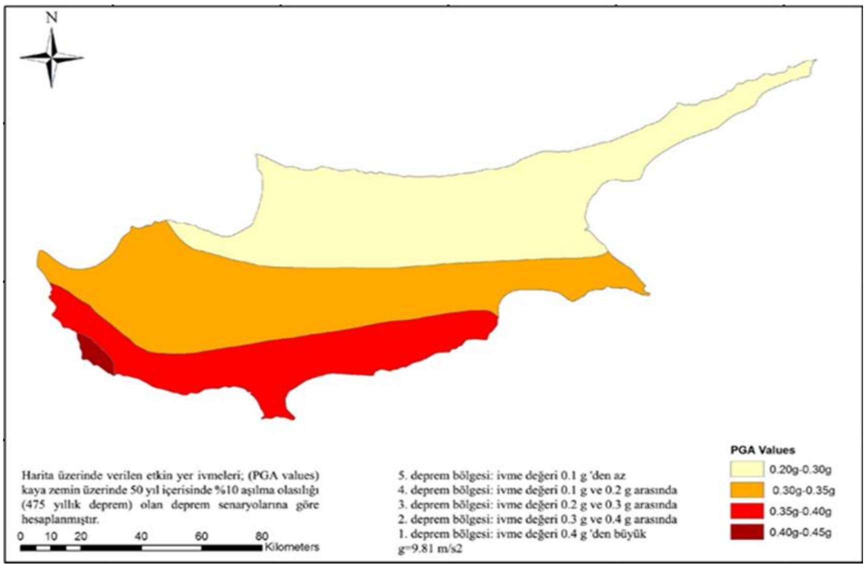

Fig. 6. Seismic zoning map of Cyprus from NCSC 2015.

1.2. Objective of work

The main objective of this paper is to investigate the regular and irregular RC framed buildings located in Nicosia city and explore the variations in the results obtained using the two seismic design codes, i.e., EC 8 and NCSC 2015. The 3D analysis is carried out under static and dynamic seismic analysis in both x and y directions. ELFM and RSM have been used for performing static and dynamic analysis respectively. The methods were used to verify the seismic design base shear, storey shear, axial force and moments for selected columns under different parameters suggested by codes mentioned above.

2. Modelling of RC Framed Structures and Case Study

The location of the building is assumed to be at Nicosia city of northern Cyprus. The investigated reinforced concrete frame building is designed as per the considered seismic codes and the corresponding design codes. The design codes are Eurocode 2 (EC2) [13] and Turkish standards (TS 500) [14] respectively.

The total height of the building above the ground level considered for the study is 15.6 m. In the present study, ground (*G*) +4 storey RC residential building of 21.5 m × 14.5 m in plan has been considered for the comparison, as shown in Fig. 7.

Four types of RC buildings have been modelled and analysed in this study, namely:

A. Ground+4 storey regular frame analysis using ELFM.
B. Ground+4 storey regular frame analysis using RSM.
C. Ground+4 storey irregular frame analysis using ELFM.
D. Ground+4 storey irregular frame analysis using RSM.

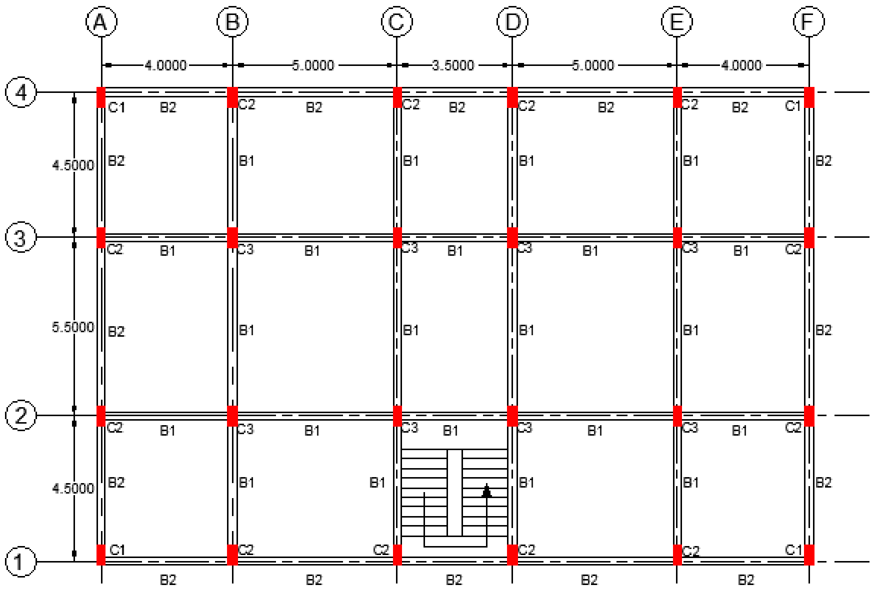

Fig. 7(a). Floor plan for *G*+4 storey regular RC frame.

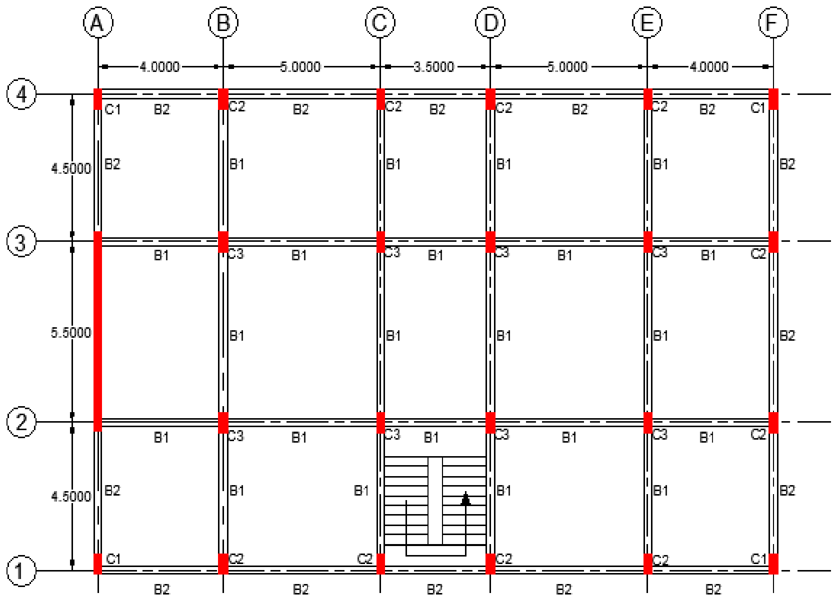

Fig. 7(b). Floor plan for *G*+4 storey irregular RC frame.

The reinforced concrete building data are used as a program input data to design multi-storey buildings according to EC 8 and NCSC 2015 rules and limitations. In general, there are two types of details used for the residential building design, which are general building data and specific building data. The general building data are common between EC 8 and NCSC 2015 for the investigated buildings, as shown in Table 1.

Table 1. General residential building datas.

	Data
Importance factor (I)	1.0
Allowable bearing pressure*	200 kN/m²
Modulus of subgrade reaction*	20000 kN/m³
Concrete density	25 kN/m³
Earthquake analysis method	ELFM and RSM
Type of foundation	Single foundation

*According to soil investigation report for Nicosia, which has been done by geology and mines department of northern Cyprus [15].

Theoretically, seismic ground motions are shown by elastic acceleration spectrum in both seismic codes. Spectrum characteristic periods are defined due to the local ground conditions. For the investigated buildings, the specific building details according to EC 8 and NCSC 2015, are shown in Tables 2 and 3, respectively.

Table 2. Specific residential building details according to EC 8.

Investigated building	Detail
Seismic zone coefficient ($a_g R$)	0.2 g
Spectrum characteristic period (T_b/T_c)	0.2/0.6
Concrete Design Code	EC 2

Table 3. Specific residential building details according to NCSC 2015.

Investigated building	Detail
Seismic zone coefficient (A_o)	0.3 g
Spectrum characteristic period (T_a/T_b)	0.15/0.4
Concrete design code	TS 500

The typical floor height of RC building is 3 m and all storeys are considered as typical floors. The compressive strength of concrete was considered as 30 MPa and the yield strength of the steel was selected as 420 MPa. The damping ratio was taken as 0.05 and typical slab thickness was 150 mm. The dimension of slabs, beams and columns are given in Tables 4 to 6 respectively. In the frame buildings, some members were selected for the aim of the analysis. The selected column members (corner, exterior, interior) are shown in Table 6.

Table 4. Layout of slab for the residential building.

Number of storey	Slab type	Thickness (mm)	Description of slab
***G*, 1-4**	S1	150	Slab carrying internal walls
	S2	150	Slab for stairs

Table 5. Layout of beams for residential building.

Number of storey	Beam type	Dimensions (mm)	Type of carrying
***G*, 1-4**	B1	500*250	Internal walls
	B2	500*250	External walls

Table 6. Layout of columns for residential building.

Number of storey	Column type	bx (mm)	by (mm)
***G*, 1-4**	Corner column (*C*1)	300	400
	Exterior column (*C*2)	300	500
	Interior column (*C*3)	300	600

The analysing and designing of the RC buildings are made by using ETABS 2015 software package. ETABS 2015 is an integrated package program of software capable of executing three dimensional (3D) analysis.

The isometric view of the *G*+4 storey regular and irregular RC buildings are presented in Fig. 8.

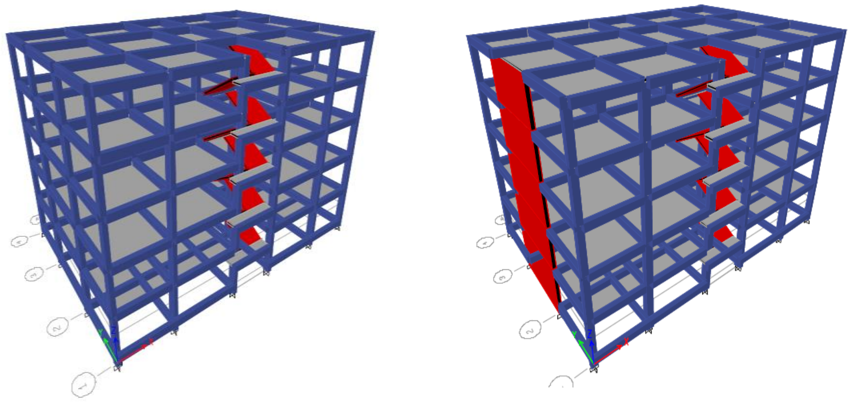

Fig. 8. View of 3D model of *G*+4 storey regular and irregular RC frame.

According to Resatoglu and Atiyah [16], currently, all seismic design codes take into account the effect of inelastic energy dissipation by reducing the design seismic force by a response reduction factor also called behaviour factor. For the case study, the high ductile design has been chosen for both codes.

EC 8 defines it as behaviour factor (q) and NCSC 2015 defines it as ductility reduction factor (R). For the case study, the provided reduction factors according to EC8 and NCSC 2015, which are used to design and analyze the buildings is shown in Table 7.

Table 7. Reduction factors according to (NCSC 2015, EC 8).

Seismic design code	Reduction factor
NCSC 2015 (Resisted by frame)	$R = 8$
NCSC 2015 (Resisted by shear wall)	$R = 7$
EC 8 (Resisted by frame)	$q = 5.85$
EC 8 (Resisted by shear wall)	$q = 5.4$

According to a recent United Nations seismic hazard research in Nicosia region, the estimated peak ground acceleration is 0.32 g with 10% probability exceedance in 50 years and the lowest shear wave velocity for Nicosia is 209 m/s [17].

Based on studies by Safkan [18], this research also considers the contribution of side effects. According to NCSC 2015 and EC 8, ground types, which have a big effect on the behaviour of structures under earthquake load is given in Table 8 as shown below.

Table 8. Ground-type description according to (NCSC 2015, EC 8).

Soil type		Definition	
NCSC 2015	**EC8**	**NCSC 2015**	**EC8**
***Z*1**	*A*	Very dense sediment, gravel and solid clay vs. < 700 m/s	Rock or other rock-like geological formation vs. > 800 m/s
***Z*2**	*B*	Dense sediment gravel, very stiff clay 300 m/s < vs. < 700 m/s	Deposits of very dense sand, gravel, or very stiff clay 360 m/s vs. < 800 m/s
***Z*3**	*C*	Medium dense sediment and gravel, stiff clay 200 m/s < vs. < 300 m/s	Deep deposits of dense or medium dense sand, gravel or stiff clay 180 m/s < vs. < 360 m/s
***Z*4**	*D*	Weak sediment, soft clay with alluvium layer high water table vs. < 200 m/s	Deposits of loose-to-medium cohesionless soil vs. < 180 m/s
	E		A surface of alluvium layer with water table a layer of type *C* or *D* on rock
–	*S*1	–	A layer of at least 10 m thick soft clays/silts
–	*S*2	–	Sensitive clays, or any other soil profile not included in types *A* – *E* or *S*1

As can be seen from Table 8, and the information obtained from soil investigation report for Nicosia, which has been done by geology and mines department of northern Cyprus, the Nicosia region (northern part of the island), has average soil class *C*. Due to class type *C*, EC 8 suggests 0.2 g and NCSC 2015 map shows 0.3 g for Nicosia city. It should be noted that there are two special ground types *S*1 and *S*2, which have been described in EC 8.

The load combinations in Table 9 for each seismic code were utilised also in the modelling of RC framed structures. The different load combinations for 3D analysis is considered in both seismic codes as it is shown in Table 9. NCSC 2015 and EC 8, considered the effects of lateral forces in two directions.

Table 9. Load combinations.

Case	NCSC 2015	EC8
DL* and *LL	1.4 *DL* + 1.6 *LL*	1.35 *DL*+1.5 *LL*
DL* , *LL* and *E	1.0 *DL* +1.0 *LL* ± 1.0 E_X	1.0 *DL*+0.3 *LL* ± 1.0 E_X
	1.0 *DL* + 1.0 *LL* ± 1.0 E_Y	1.0 *DL*+0.3 *LL* ±1.0 E_Y
	1.0 *DL* +1.0 *LL* ± 1.0 E_X ± 0.3 E_Y	1.0 *DL*+0.3 *LL* ± 1.0 E_X ± 0.3 E_Y
	1.0 *DL* +1.0 *LL* ± 0.3 E_X ± 1.0 E_Y	1.0 *DL*+0.3 *LL* ± 0.3 E_X ± 1.0 E_Y
DL* and *E	0.9 *DL* ± 1.0 E_X	-
	0.9 *DL* ± 1.0 E_Y	-

3. Results and Discussions

The comparison of base shear, storey shear, axial forces and moments for selected columns for two different codes. Graphical representation has been shown in the following Figs. 9 to 16.

3.1. Base shear

The total base shear using ELFM and RSM for two types (regular and irregular) of RC framed structures has been adopted for different codes for the case region. Figures 9 and 10 show the obtained base shear in the *x* and *y* directions, using both static and dynamic procedures.

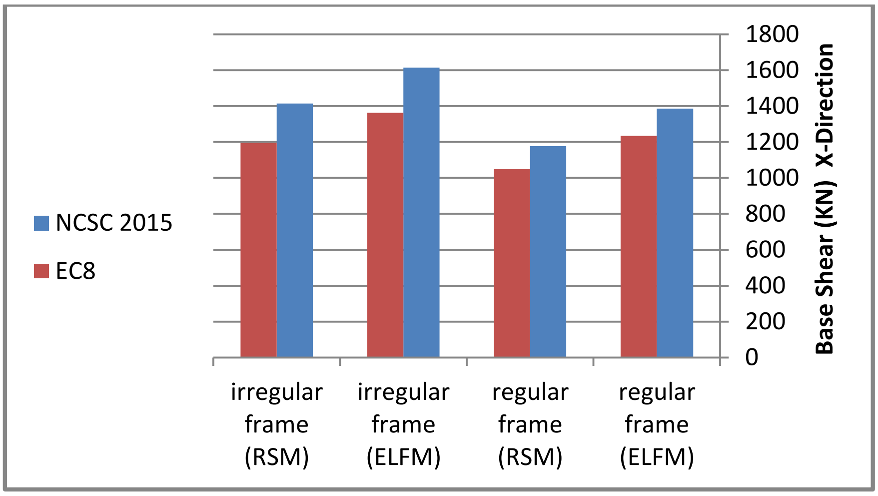

Fig. 9. Total base shear in *x*-direction.

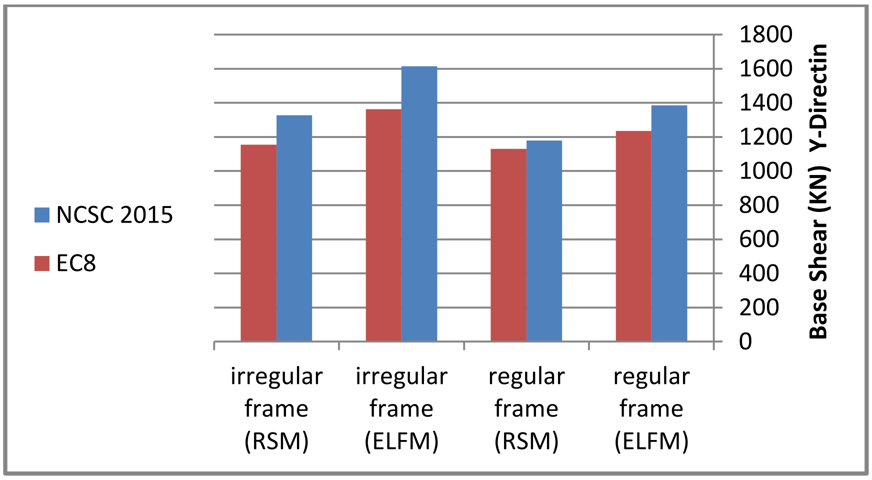

Fig. 10. Total base shear in *y*-direction.

The total base shear obtained from ELFM (*G*+4 storey regular frame) is about 15% higher than that of RSM (*G*+4 storey regular frame) in the *x*-direction. The total base shear obtained from ELFM (*G*+4 storey irregular frame) is about 13% higher than that of RSM (*G*+4 storey irregular frame) in the *x*-direction. The same observation was made in the *y*-direction for a regular frame. For *G*+4 storey irregular frame, the total base shear in the *y*-direction decreases by 9% from ELFM to RSM.

3.2. Storey shear

The graphs for storey shear versus storey height are made for both codes and for all RC buildings (regular and irregular) using ELFM and RSM. The results are shown in the following Figs. 11 to 14.

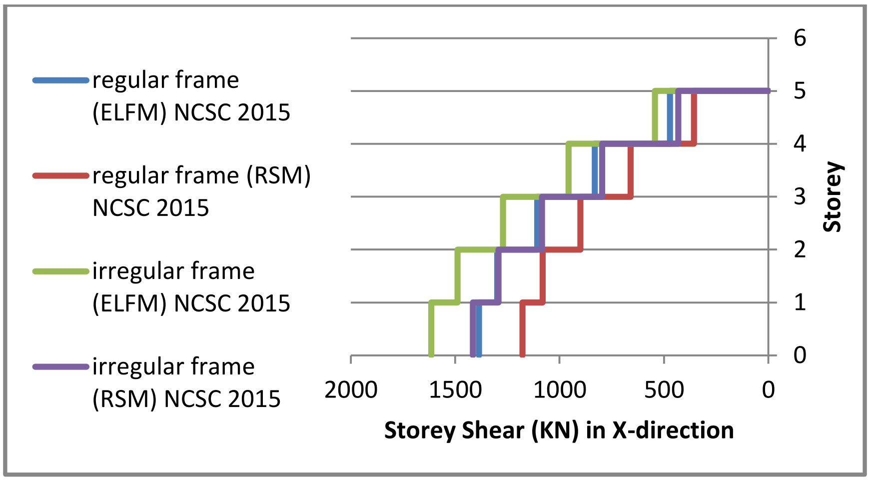

Fig. 11. Storey shear according to NCSC 2015 in *x*-direction.

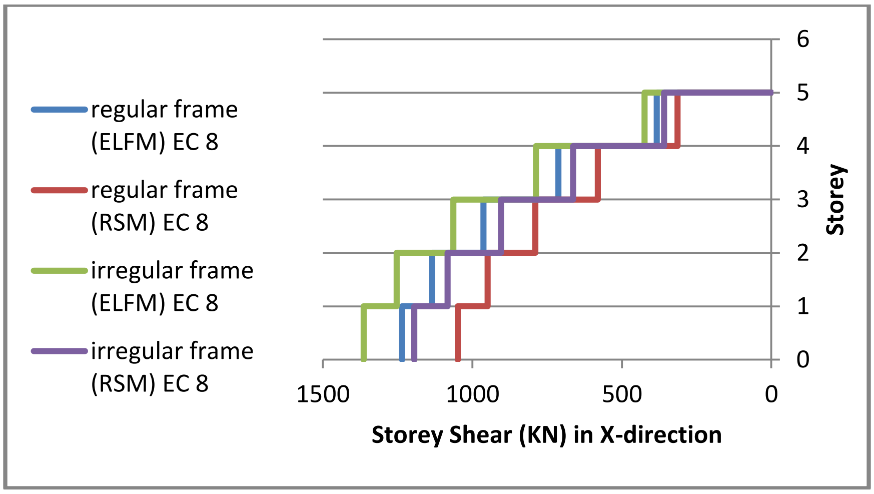

Fig. 12. Storey shear according to EC 8 in *x*-direction

The storey shear in *x*-direction using NCSC 2015 and EC 8, for ELFM (regular frame and irregular frame) the values varies from 15% to 24% higher than that of RSM.

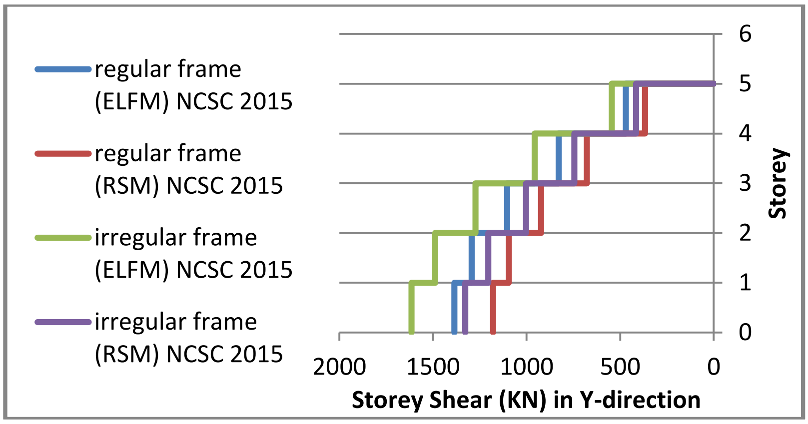

Fig. 13. Storey shear according to NCSC 2015 in *y*-direction.

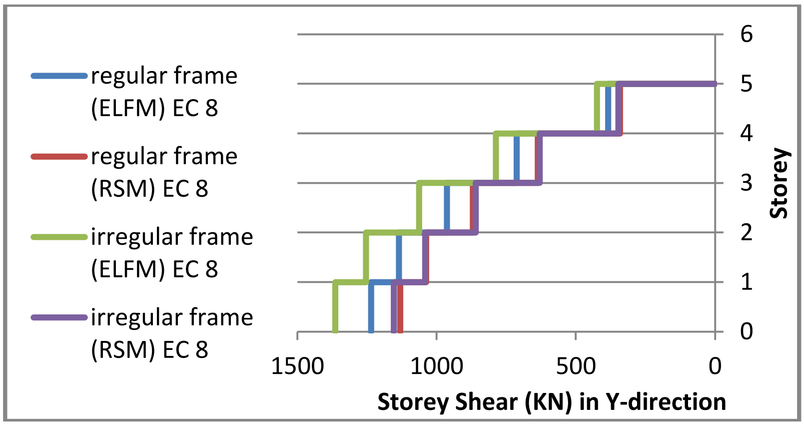

Fig. 14. Storey shear according to EC 8 in *y*-direction.

The storey shear in *y*-direction using NCSC 2015 and EC 8, for ELFM (regular frame and irregular frame) the values varies from 9% to 22% higher than that of RSM.

3.3. Axial forces in columns

The column axial force is analysed and chosen columns *C*1 (corner), *C*2 (exterior), *C*3 (interior) using ELFM and RSM for two types (regular and irregular) of RC framed structures has been adopted for different codes for the case region. Figure 15 shows the results of the column axial force for a corner, external and interior column.

The total axial force obtained from ELFM (*G*+4 storey regular frame) using NCSC 2015 is about 8%, 12% and 2% higher than that of RSM (*G*+4 storey regular frame) for *C*1, *C*2 and *C*3, respectively. The total axial force obtained from ELFM (*G*+4 storey regular frame) using EC 8 is about 2%, 13% and 1% higher than that of RSM (*G*+4 storey regular frame) for *C*1, *C*2 and *C*3, respectively. The total axial force obtained from ELFM (*G*+4 storey irregular frame) is about 7%, 1%, 1% higher than that of RSM (*G*+4 storey irregular frame) for *C*1, *C*2 and *C*3, respectively for both codes.

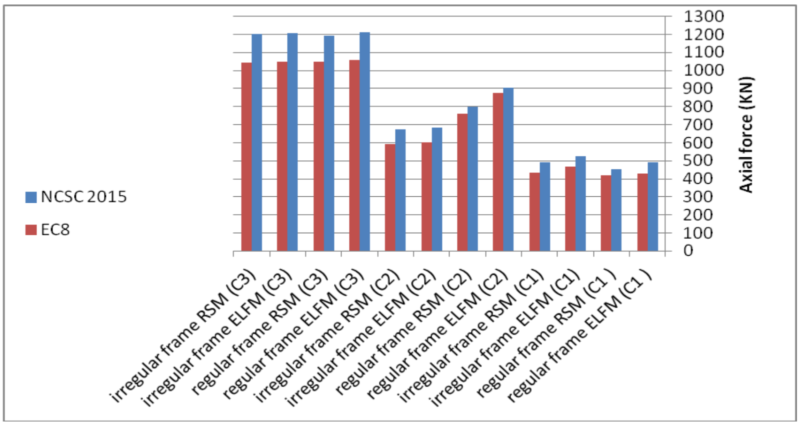

Fig. 15. Axial forces (kN).

3.4. Bending moments in columns

The maximum column bending moment is analysed and chosen columns *C*1(corner), *C*2(exterior), *C*3(interior) using ELFM and RSM for two types (regular and irregular) of RC framed structures has been adopted for different codes. Figure 16 shows the results of maximum column bending moments for a corner, external and interior column.

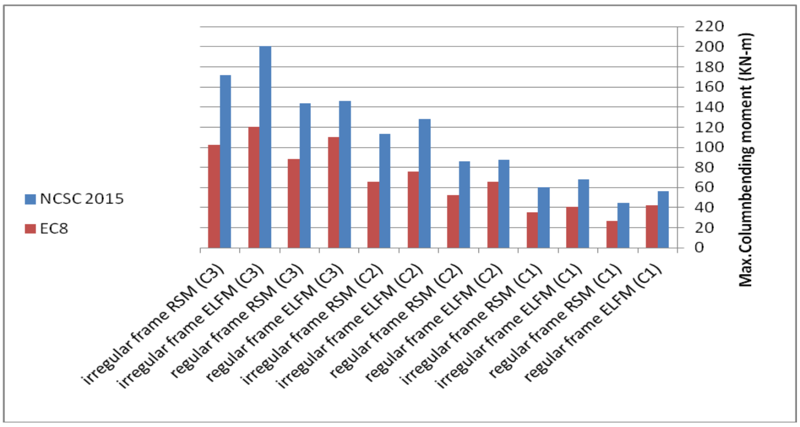

Fig. 16. Maximum bending moments (kN-m).

The maximum column bending moment obtained from ELFM (*G*+4 storey regular frame) using NCSC 2015 is about 20%, 2% and 2% higher than that of RSM (*G*+4 storey regular frame) for *C*1, *C*2 and *C*3, respectively. The maximum column bending moment obtained from ELFM (*G*+4 storey regular frame) using EC8 is about 37%, 20% and 20% higher than that of RSM (*G*+4 storey regular frame) for *C*1, *C*2 and *C*3, respectively. The maximum column bending moment obtained from ELFM (*G*+4 storey irregular frame) using NCSC 2015 is about 12%, 12% and 14% higher than that of RSM (*G*+4 storey irregular frame) for *C*1, *C*2 and *C*3, respectively. The maximum column bending moment obtained from ELFM (*G*+4 storey irregular frame) using EC8 is about 13%, 13% and 15% higher than that of RSM (*G*+4 storey irregular frame) for *C*1, *C*2 and *C*3, respectively.

4. Conclusions

Finally, it can be said that this study conveys the following conclusions:

- The design base shear as per EC 8 is similar to that of NCSC 2015. However, response reduction factors (or behaviour factors) vary in each seismic code and have an effect on total base shear. In the case of base shear, the dynamic result is about 85% and 87% of static analysis for a regular and irregular frame, respectively.
- It is clear from the storey shear results that the ELFM gives higher values in both directions rather than the RSM results.
- Axial force in columns as per EC 8 is similar to that of NCSC 2015. The different load combination factor in each seismic code has an effect on total axial load in columns. For using regular frame the results obtained from dynamic RSM are about 92%, 88% and 99% of static ELFM for corner column, exterior column and interior column respectively.
- In the case of column bending moment, the results obtained from dynamic RSM are about 86%, 87% and 85% of static analysis for corner column, exterior column and interior column respectively.
- The ELFM works well for low to medium rise buildings. However, the results of ELFM are approximately uneconomic. Because the design parameters such as base shear, storey shear, axial force and bending moment values are higher than RSM.
- It is not compulsory to use of Eurocodes in northern Cyprus as it is in southern. The current standard for the requirement for design and construction of RC structures is Turkish Standard (TS500) and the current earthquake code NCSC 2015 used in the northern part of the island is actually based on Turkish Earthquake Code 2007 (TEC2007). In order to provide common design criteria, format, notation and increase the understanding regarding the design of structures between the owners, operators, users, designers and contractors, the use of Eurocodes would be appropriate during the entry process of north Cyprus to European Union. In addition, harmonisation with international structural design practice should be improved in north Cyprus where the National annexes exists for the whole island already.
- Moreover, to generalize the results obtained, an analysis of a satisfactory number of buildings with a different number of storeys and irregularities should be made.

Nomenclatures

a_gR, A_0	Seismic zone coefficient
DL	Dead load
E	Earthquake load
I	Importance factor
LL	Live load
R	Response reduction factor (behaviour factor)
T_a, T_b, T_c	Spectrum characteristic period

Abbreviations

EC 2	Eurocode 2
EC 8	Eurocode 8
ELFM	Equivalent Lateral Force Method
ETABS	Extended Three Dimensional Analysis of Building System
NCSC 2015	Northern Cyprus Seismic Code 2015
PGA	Peak Ground Acceleration
RC	Reinforced Concrete
RSM	Response Spectrum Method
TEC2007	Turkish Earthquake Code 2007
TS 500	Turkish Standard 500

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